

Plano de Pesquisa

Investigação experimental do espalhamento tipo arco-íris nos canais elástico e de transferência de partículas alfa na reação de $^{16}\text{O} + ^{60}\text{Ni}$

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Resumo:

Planeja-se a medida com o espectrômetro MAGNEX [1] da reação de $^{16}\text{O} + ^{60}\text{Ni}$ a 280 MeV de energia do feixe, fornecido pelo acelerador Ciclotron Supercondutor dos Laboratórios Nacionais do Sul, Catania, Itália. O objetivo é verificar as previsões de ocorrência de espalhamento tipo arco-íris, baseada em cálculos de canais acoplados com modelo óptico fundamentado no Potencial de São Paulo.

Introdução:

O Arco-Íris Nuclear é um fenômeno análogo ao arco-íris atmosférico, observado desde longa data no espalhamento elástico em sistemas relativamente leves. Classicamente, o arco-íris é determinado pela presença de um máximo ou um mínimo na função deflexão $\Theta(l)$. Normalmente, no caso de espalhamento nuclear, um máximo ocorre na região de $\Theta > 0$ (chamado arco íris Coulombiano), enquanto que, devido ao caráter atrativo da força nuclear a distâncias da ordem de alguns fm, um mínimo ocorre na região de $\Theta < 0$ (arco íris nuclear). Em sistemas leves como $^{12}\text{C} + ^{12}\text{C}$; $^{12}\text{C} + ^{16}\text{O}$; $^{16}\text{O} + ^{16}\text{O}$; e partículas alfa em núcleos de diversas regiões de massa, o espalhamento elástico apresenta um aumento em ângulos grandes, associado a contribuições de diversas ondas parciais, algumas vezes evidenciando a presença de mínimos de Airy, característicos do arco-íris. Classicamente, as trajetórias envolvidas na formação do arco-íris são as que sofrem influência da região mais interna, atrativa, da superfície nuclear, do lado oposto, ou “afastado” do detector (*far-side trajectories*). O arco íris nuclear é portanto sensível a regiões internas do potencial, e daí a sua importância como teste de modelos nucleares. Em núcleos mais pesados, em que há maior absorção, o efeito tende a desaparecer. No entanto, descobrimos recentemente que o efeito do acoplamento aos primeiros estados excitados do núcleo alvo pode resultar em distribuições angulares com características muito semelhantes às dos casos em que há arco íris. As previsões do modelo utilizado para o sistema $^{16}\text{O} + ^{27}\text{Al}$ a 100 MeV foram confirmadas até um ângulo de cerca de 80 graus no centro de massa [2-5]. Dados do mesmo sistema a 280 MeV [6] também indicam a existência de arco-íris, embora em região angular um pouco diferente das previsões teóricas [7]. O objetivo do experimento será explorar sistemas de massa ainda mais alta.

Medidas de $^{16}\text{O} + ^{60}\text{Ni}$ a 280 MeV:

No presente experimento, pretendemos estender o mesmo tipo de medidas para o sistema $^{16}\text{O} + ^{60}\text{Ni}$, a 280 MeV, para o qual há previsões de um aumento muito intenso da seção de choque em ângulos grandes devido ao acoplamento de canais, no canal elástico, e espalhamento tipo arco íris também no canal de transferências de partículas alfa. O experimento será executado com o espetrômetro MAGNEX, que permitirá separar os canais elástico e inelásticos, e o feixe, à energia de 280 MeV, será fornecido pelo acelerador Supercondutor CS dos LNS/INFN (Catania, Itália).

Agendamento do experimento

O experimento proposto foi aprovado pelo comitê de avaliação de programas (CAP) dos LNS e está agendado para ser realizado entre os dias 1 a 1 de dezembro de 2014.

Mais detalhes sobre a proposta e o planejamento do experimento encontram-se no anexo (em inglês) que contém a proposta apresentada ao CAP dos LNS.

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Experimental investigation of rainbow-like scattering in the elastic and alpha transfer channels of the $^{16}\text{O} + ^{60}\text{Ni}$ reaction

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ABSTRACT

We propose to measure elastic, inelastic, and transfer angular distributions of the $^{16}\text{O} + ^{60}\text{Ni}$ reaction at 214 and 280 MeV with the MAGNEX spectrometer of the LNS in order to investigate the occurrence of rainbow-like scattering, particularly in the elastic channel and alpha transfer to $I^P=0^+$ states (at the beam energy of 280 MeV), as theoretically predicted by coupled channel calculations based on the São Paulo Potential. If the predictions are confirmed, rainbow like structures will be observed for the first time, contrary to common expectations, in a heavier than $^{16}\text{O} + ^{27}\text{Al}$ system, and in particle transfer channels.

Introduction

Nuclear rainbow phenomena has been observed long ago in alpha-nucleus scattering and in a few relatively light systems such as $^{12}\text{C} + ^{12}\text{C}$, $^{16}\text{O} + ^{12}\text{C}$ and $^{16}\text{O} + ^{16}\text{O}$ (see *e.g.* [1] for a review). Very recently, rainbow-like scattering has also been observed, with the MAGNEX spectrometer, in the heaviest system so far, $^{16}\text{O} + ^{27}\text{Al}$ at 100 MeV [2,3] at the Tandem accelerator, and at 280 MeV [4] at the Superconducting Cyclotron CS of the LNS. This result was predicted for such heavy systems, in spite of the strong absorption expected, by coupled channel calculations (CC) based on the São Paulo Potential (SPP) and the Glauber model [5]. The same type of calculations support the present proposal.

Figure 1 presents our theoretical results for the $^{16}\text{O} + ^{60}\text{Ni}$ reaction at three different energies. For the one at 141 MeV, the calculations [5] agree well with the available experimental data [6] up to around 40° in the CM system. The increase of several orders of magnitude in cross section as the beam energy increases is to be noted above, say, 30°. This increase allows for the experimental exploration of this angular region for the two highest energies shown.

Figure 2 shows in more detail the predictions for the $^{16}\text{O} + ^{60}\text{Ni}$ reaction at 280 MeV. The purple solid curve in Fig. 2 is the SPP/CC calculation result for the elastic scattering angular distribution, while the cyan dashed curve is the corresponding Optical Model with no couplings (SPP/OM) prediction according to the prescriptions of ref. [7]. A relative enhancement of several orders of magnitude is apparent in the CC above 25° (CM) relative to the OM one, as a result of the coupling of the ground state to the first excited states of the

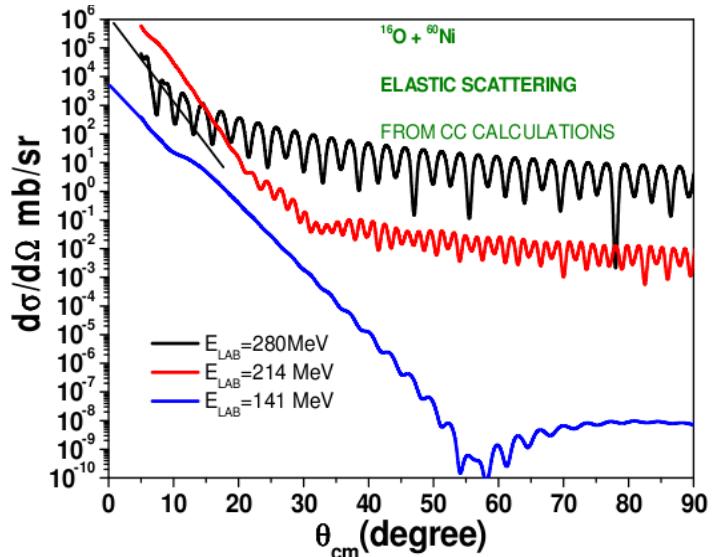


Figure 1: Elastic angular distributions for the $^{16}\text{O} + ^{60}\text{Ni}$ reaction at three different energies.

target. Such couplings are connected to the formation of rainbow-like structures as discussed in [3]. In addition, a clear rainbow-like “far-side” bump above 25° is also observed in the alpha transfer to the 0^+ ground state of ^{64}Zn . This characteristic feature is absent for the 2^+ state at 0.99 MeV of ^{64}Zn (light brown curve). To our knowledge this is the first theoretical prediction of such kind of phenomena.

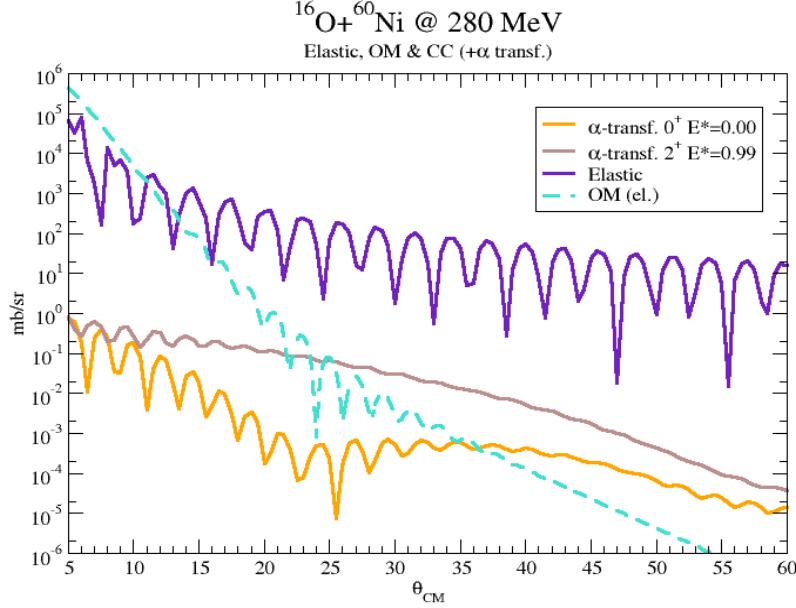


Figure 2: Center of mass (CM) angular distributions calculated with the model of ref. [4].

Figure 2 presents the results for the angular distributions of all the inelastic and transfer states included in the CC calculations. From this figure it can be seen that rainbow-like scattering is present only for alpha transfer to 0^+ states, certainly in connection with the coupling to higher-lying states of ^{64}Zn .

The choice of the target

The CS cyclotron beam of ^{16}O with good resolution and intensity has already been used at the energy of 280 MeV (for the $^{16}\text{O} + ^{27}\text{Al}$ system), where the rainbow-like features are clearly established according to the calculations for the $^{16}\text{O} + ^{60}\text{Ni}$ system. The target is considerably heavier than ^{27}Al and the test of the predictions will be very strong. The nucleus of ^{60}Ni has been extensively investigated experimentally, near and above the barrier [6,8]. The coupling strengths to all relevant channels have been well established, and the calculations are able to predict with good precision the experimental elastic scattering angular distribution data up to the highest energy published in the literature [6]. The choice of this isotope of Ni seems therefore quite appropriate for the experiment.

Objectives of the proposal

The main purpose of this proposal is to verify such unexpected predictions and evaluate the degree to which the theoretical calculations are correct. It will be very important to verify the predicted variation with the energy of the beam of the elastic cross section at large angles. For this reason we intend to measure at the two beam energies: 214 and 280 MeV. If the predictions are verified, it will be the first time in which rainbow-like phenomena appears in so heavy systems, and in alpha transfer scattering (at 280 MeV). The strong sensitivity to the angular momentum transferred (0^+ states) will be also seen for the first time in heavy ion reactions. The expected energy resolution should be enough to easily separate the ground-state of ^{64}Zn from the first excited state (2^+).

Beam time request

For the performance of the experiment we need about 33 BTU (including a day of setup) in total.

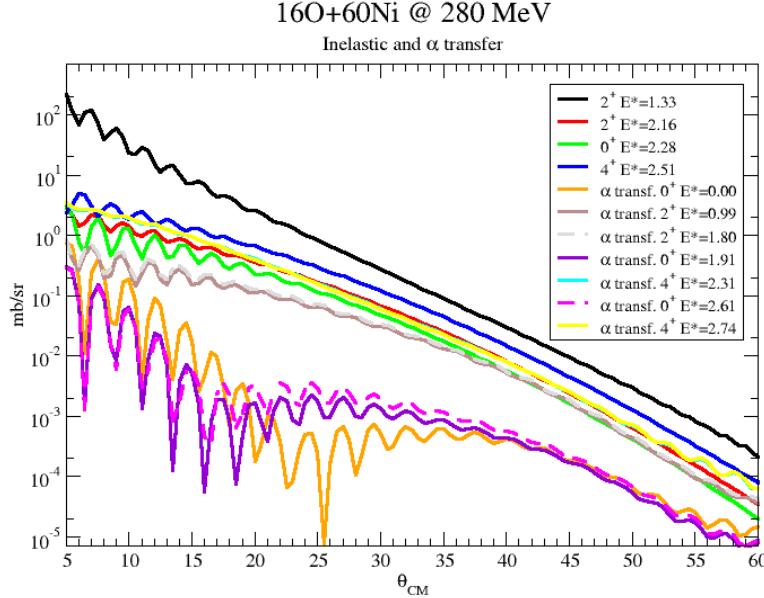


Figure 3: Angular distributions (CM) for inelastic and transfer states.

Considering a typical cross section of 500 nb for the most difficult case of alpha transfer to gs around 30° in the CM (24.6° at the lab.), with 10pnA of ^{16}O on a $200\mu\text{g}/\text{cm}^2$ ^{60}Ni target, we estimate a statistical uncertainty of about 30% after 3 BTU (1 day) of data acquisition for an angular integration of 1 degree in the focal plane of MAGNEX. With 9 BTU the angular range from 5° to 40° (CM) can be measured considering 12° coverage of MAGNEX (3 steps, with essentially no overlap – a monitor should be used for adequate normalization).

For the elastic scattering data, with cross sections of 2 and 4 orders of magnitude larger than the α -transfer to gs, at 214 and 280 MeV, respectively, and with the usual overlap of 50% between angular range measurements, we require 6 and 15 BTU, respectively. We intend, with this request, to be able to measure data points with 15% statistical uncertainty at 214 MeV (half-degree intervals), and 5% (0.25 degree intervals) at 280 MeV, in order to be able, in this last case, to characterize the large expected cross section oscillations in the angular distribution in the 5° to 40° (CM) angular range.

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